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# CONTRIBUTIONS OF THE APOLLO MATERIALS SELECTION AND TEST PROGRAM TO FUTURE MANNED SYSTEMS

## INTRODUCTION

This paper summarizes the significant results of the Apollo nonmetallic materials selection and test program, and discusses some present and anticipated uses of these results for other manned systems. The accomplishments of the organized, intense, and continued efforts to provide fire-resistant spacecraft for the Apollo Program have already been applied to other manned space programs such as the Manned Orbiting Laboratory and Apollo Applications Programs, and will provide, in the future, widespread benefits in other areas such as medical technology.

## APOLLO PROGRAM ACCOMPLISHMENTS

Apollo combustion investigations related to the use of nonmetallic materials in spacecraft cabins have produced a number of significant accomplishments. For instance, advanced flame-resistant materials have been discovered and developed; selection criteria and uniform sample test procedures have been improved and standardized; full-scale test methods have been perfected; ignition, combustion and toxicity data have been generated and collated for a large number of materials; fire extinguishing methods have been studied and an effective extinguisher developed; and some beginning contributions have been made to flammability prediction techniques.

### Flame-Resistant Materials

A broad range of flame-resistant materials have been perfected within the last year in response to Apollo Program needs. For example, Beta-cloth material, with improved, non-flammable coatings and increased abrasion resistance, is used to weave fabrics, webbings, tapes, and braids, as well as to make mats, felts, filters, and insulation materials. Fluorocarbons, such as Teflon, which possess a high degree of chemical resistance, are used for wire insulation and in many new applications such as food packages. A nonflammable fluorel material has been developed, which can be used to protectively isolate flammable materials, such as the silicon rubber oxygen hoses. This material is inexpensive and should be readily adaptable to other applications.

These examples represent only a few of the nearly one hundred improved materials applications developed for Apollo usage. One significance of such materials developments to other applications lies in the fact that materials become increasingly flame resistant as the partial pressure of oxygen in their usage environment diminishes. Therefore, materials that meet Apollo's demanding requirements for pure oxygen exposure will be highly flame resistant, perhaps nonflammable, in lesser oxygen-content atmospheres, such as in airplanes or automobiles.

### Test Procedures

In general, nonmetallic materials proposed for spacecraft usage are first tested separately in standard size samples, then in subassemblies and manufactured parts, and finally in full-scale boilerplate vehicle tests. This procedure permits the identification of the fire resistance of the materials themselves, as well as possible synergistic effects of the installed configurations.

The extensive test work has stimulated the development and standarization of test techniques. Thus the results of tests performed by different organizations in different locations can be compared and materials evaluated on the basis of common test techniques. In addition to the standardization of sample test techniques, several new test methods have been developed. For example, the problems of measuring flame speed during tests of the effects of acceleration on burning have encouraged improvement in the instrumentation and operation of such tests.

Full-scale combustion experience has also contributed to techniques which will be applicable to other vehicle systems. The Apollo full-scale spacecraft tests have as their purpose the validation of the combustion safety, prior to manning, of specific Apollo spacecraft. The tests are conducted in full-scale mockups of specific spacecraft so that the combined effects of materials selection and placement can be evaluated. The tests completed,

thus far, have confirmed the redesigned cabin's combustion resistance in all but a few cases, for which remedial steps have been taken. During a recent Combustion Institute conference, it was the consensus that, at present, full-scale ignition tests are the best way of getting dependable, practical, combustion information. Therefore, the development of full-scale flame propagation test techniques will remain important as a design verification tool for some time for both Apollo and for other applications.

#### Combustion Data

A central effort of the Apollo materials selection program has been the production and orderly tabulation of ignition and combustion data on nonmetallic materials. As a result of this effort, there is now, in COMAT (Characteristics of Materials Test Data Listing), the largest existing collection of data on combustion characteristics of practical materials in oxygen. The listing includes such data as the oxygen pressure under which the test was made (5.0, 6.2 or 16.5 psia), ignition temperature, the rate and direction of burning (up or down), and the amount of gas given off when the material is heated (off gassing) for about 2800 specimens. The data is produced by both NASA and the prime contractors using the NASA uniform test procedures. COMAT data is continuously updated and listed in a manner enabling rapid

retrieval of more detailed data. In addition to NASA, COMAT is distributed to many contractors and a large number of government agencies in order to make available to potential users the results of the Apollo tests.

The effects of acceleration fields on combustion of some select materials have been studied in 1 to 15 g tests at the White Sands Testing Facility and elsewhere, as well as during limited zero-g tests. This newly generated data has been widely distributed.

Combustion of nearly all materials produces poisons. It is necessary that materials for manned spacecraft use be selected to prevent unacceptable toxic concentrations as a result of a fire. Therefore, the standard material tests include a measure of pyrolysis and combustion products, and the carbon monoxide, total organics, and odor evaluation results are included in COMAT. In addition, during full-scale tests, atmosphere sampling for toxicity analysis has been conducted. The accumulated data, especially on the fire-resistant materials, will be directly useful to a large variety of manned systems.

#### Fire Extinguishment

A large variety of fire extinguishing agents and methods have been tested and evaluated for use in manned spacecraft. Many agents considered effective in an air environment, e.g., Freon 1301, were found to be much less effective in a pure oxygen

environment. NASA and its contractors have successfully developed an aqueous-gel extinguisher which is extremely effective in the pure oxygen environment, and, of course, would be even more effective in air. Because this extinguisher uses water as its basic material and was developed under NASA contract, it offers promise as an extremely inexpensive, effective household fire extinguisher, as well as for other manned systems.

#### Flammability Theory

The program effort includes an attempt to integrate present knowledge into a general combustion theory. Work at Atlantic Research and General Electric has produced progress toward understanding combustion including flame spread, flame height, and the effect of parameters such as acceleration. Research on both chemical and static-discharge ignition has already advanced understanding of these complex mechanisms. It has been possible to develop mathematical models for simple situations which allow estimates of such combustion parameters as the time rate of energy release. However, more refinement of theories is necessary for complex situations.

The full-scale mock-up tests have generated a large quantity of data on ignition and propagation characteristics for practical materials, shapes, and assemblies. This test data

is being used in the construction and verification of mathematical flammability prediction models. History has shown that the accumulation of a large body of logically ordered experimental knowledge has been a stimulus toward theoretical explanation and integration of this newly acquired experimental knowledge. There is every reason to believe that the accumulation of data by the Apollo Program will similarly stimulate the refinement of flammability theory, which then will be useful to other advanced manned systems.

#### Handbook

Another result of Apollo Program efforts now planned will be a handbook on nonmetallic materials for spacecraft. This handbook is planned to summarize the findings of the program and the latest technical literature in a form for the greatest general usefulness.

#### Potential Program Extensions

The Apollo materials selection and combustion test program has resulted in contributions to future manned systems. However, there remains a clear path for additional work. Nonmetallic materials testing could be extended to non-Apollo materials and pressures other than the values of interest to Apollo. More high-g and zero-g data should be generated and toxicity and pyrolysis measurements should be extended. The overall and gross



deficiency of the available combustion theory, characteristic not only of this program but of combustion technology in general, has not yet been appreciably repaired by the program efforts in this direction.

### EXTRA-APOLLO BENEFITS

#### Post-Apollo NASA Programs

The manned flight hardware for post-Apollo will include various combinations of the Apollo Command and Service Module and Lunar Module with other support stages. Apollo hardware will, of course, be used or modified for use wherever possible. The results of the Apollo Program are directly and immediately useful to such following programs. For example, new materials, selection criteria, and test procedures for flame resistance developed for Apollo are being used for the spacecraft modifications and additions required for the Apollo Applications Program (AAP). The AAP reliability and quality assurance and the test requirements documents specify Apollo materials, criteria, test requirements, and procedures.

#### Manned Orbital Laboratory

The Manned Orbital Laboratory Program of the Department of Defense provides a clear example of the extra-program benefits of Apollo combustion efforts. First, the nonmetallic test results have been provided directly to the Air Force and indirectly to

MOL contractors. This test information is provided both by the COMAT listing of test results and by copies of the test reports. Apollo-generated specifications and materials-control procedures have, also, been directly applied to the MOL Program. Whenever data is required for MOL-peculiar materials, it is planned that tests will be performed at the NASA White Sands Test Facility. The present availability of Apollo data to MOL will be further enhanced by a direct link between the MSC and MOL Nonmetallic Materials Information Centers.

#### Additional DOD Applications

The Air Force and Navy engineering effort toward safer manned systems uses the materials test data (COMAT), as well as Apollo selection criteria and test procedures for non-metallic materials. Typical of the usefulness of Apollo-generated capability is the use of the MSC White Sands Test Facility for Laboratory testing as requested by USAF Materials Laboratory and the U.S. Naval Research Laboratory.

#### Other Government Agencies

The divisions concerned with fire hazards within the United States Public Health Service, National Bureau of Standards, Federal Aviation Authority and Bureau of Mines are receiving COMAT and other technical data.

### Medical Use of Hyperbaric Oxygen

The use of high pressure oxygen-enriched atmospheres for surgery has been a subject of continued and increasingly frequent experiments both on human and animal subjects. These treatments are carried out in pressurized oxygen-enriched chambers, or inside an oxygen tent in a large pressurized chamber. The treatment of various infections by exposure to a pressurized oxygen-enriched atmosphere has been widely successful. The most dramatic example has been the response of gangrene to this exposure. In high pressure (2-3 atmospheres) oxygen-enriched chambers, many other infectious growths, both in vitro and vivo, have been shown to be greatly inhibited. Wounds both in humans and animals showed an improved rate of healing; the treatment of various poisons has been successful; and shock caused by bleeding or other injury has been greatly ameliorated. Surgical procedures required for major organ transplants have been successfully carried out in a high pressure oxygen-enriched atmosphere. This has been useful in all phases of the operation, beginning with the recovery of the cadaver organ and its preparation prior to insertion.

It is understandable that one of the obstacles to more active research on this particular medical technique is the danger of increased combustibility of materials in hyperbaric and enriched-oxygen atmospheres. Therefore, the efforts made in the

Apollo Program to develop materials for fire-resistant spacecraft cabins with pure oxygen are directly applicable to this medical use of oxygen-enriched atmospheres. Apollo data is being made available to investigators in this area supported by the Department of Health, Education and Welfare. In addition, MSC has provided engineering consultation on the development of safer hyperbaric medical chambers.

#### Summary

The Apollo materials selection and combustion test program had as its objective the establishment of a safe, combustion-resistant design for the program spacecraft. No other purpose was permitted to divert effort from this most essential task. The test program was further limited by considerations of time, manpower and facilities to test under Apollo conditions. Nevertheless, the results of the program are applicable to other manned systems in three important ways. First, a large group of fire-resistant material components and installations have been developed and identified. Secondly, fire extinguishing techniques have been screened; the best is being developed and proven. Third, the accumulation of test data and techniques has made a contribution to flammability prediction to the benefit of all advanced manned systems. Some examples of the general use of Apollo accomplishments have already been identified; more will doubtlessly be forthcoming.

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